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Overview of challenges, prospects, environmental impacts and policies for renewable energy and sustainable development in Greece

Jayanta Deb Mondol [a,*], Nikos Koumpetsos [b]

[a] *Centre for Sustainable Technologies, School of Built Environment, University of Ulster, Newtownabbey, Northern Ireland BT37 0QB, UK*
[b] *Dimitriou Peristeri 6, Rododafni, Aigio T.K. 25100, Greece*

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ABSTRACT

The aim of the study was to present the current status of the electrical energy market, energy legislation, green house gas emissions, energy consumption trends and future prospects of sustainable development in Greece. The study described current issues relevant to the renewable energy sources (RES) such as the climatic factors that affect the penetration of RES into the Greek energy mix, the current regulation status, the barriers and evaluation of their contribution in the energy balance. The study also investigated the increasing power demand, emissions and energy trends in the residential sector in Greece. The paper evaluated the current status of the building stock, RES and the future energy related prospects of the Aegean Sea islands. The islands were categorized based on energy production cost, heating degree days, building characteristics and natural resources to identify islands with higher and lower renewable energy potentials. The study revealed that the islands with the higher potential energy savings in the residential sector are Lesbos, Lemnos, Samothrace, Chios, Andros, Patmos, Kea and Kimolos while at the same time, Rhodes, Naxos, Amorgos, Syros, Ios and Kythnos are those islands that present the lower potential. The study will help to propose action plans and implementation strategies in terms of residential renewable energy applications in non-grid interconnected islands in Greece.

Contents

Abbreviations: BP, British Petroleum; CHP, combined heat and power; CIA, Central Intelligence Agency; CRES, Center of Renewable Energy Sources; FIT, feed-in tariff; GDP, gross domestic product; GHG, green house gas; HDD, heating degree days; PPC, public power company; PV, photovoltaic; RES, renewable energy sources; SWHS, solar water heating system; TPES, total primary energy supply; VAT, value added tax.

* Corresponding author. Tel.: +44 2890 368037; fax: +44 2890 368239.
E-mail address: jd.mondol@ulster.ac.uk (J.D. Mondol).

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1. Introduction

Fossil fuels dominate in the global energy production market contributing 80% of the primary energy demands. Recent data indicate that annual global electricity production counts for 20.68 trillion kW h while at the same time the consumption stands for 19.01 trillion kW h [1]. At the end of 2009, the renewable energy contributed 19% to the global final energy consumption (biomass 13%, hydro 3.2%, and other sources 2.6%). This resulted in the production of about 18% of the total global electricity supply by renewable sources or in other words, with the total global power generating capacity estimated to be 4800 GW in 2009, the renewable part stood for 1230 GW [2].

The financial crisis decelerated global growth and along with it the investment interest in sustainable energy sector. Nevertheless, prospects of a new dynamic sustainable development could arise by addressing the challenges and seizing the opportunities as they arise in the new era's volatile environment. With the energy markets increasingly manipulated by gigantic multinational energy companies and with the hydrocarbons reserves accumulating in a few hands, a stable energy supply which is the basic prerequisite for recovery from the recession becomes an easy target which must be shielded from pricing and geopolitical games. A leading role in this effort can be played by the further introduction of renewable energy sources into the energy mix. Furthermore, it has to be noted that a passage to more decentralized, sustainable energy sources and adequate supplies of energy could lead to significant reduction of poverty.

The aim of the study was to review the past and current status of energy consumption, energy trends, green house gas (GHG) emissions, energy policy strategies, legislation, current renewable energy status and potential and barriers relevant to implementation of renewable energy technologies in Greece with further attention to Aegean Sea islands. The study also investigated the current general framework, regulations and feed-in tariffs (FIT) of the country and reviewed the energy production cost, heating degree days, building characteristics and natural resources to identify islands with higher and lower renewable energy potentials.

2. Overview in the Greek region

Table 1 summarizes some important indicators of Greece. The total population of Aegean Sea islands is 508,807 based on 2001 data, with urban and rural shares of 53.4% and 46.6%, respectively.

Table 1
Indicators of Greece [3,4].

Indicator	Value
Population (millions)	11.24
Energy production (Mtoe)	9.86
Net imports (Mtoe)	25.16
TPES (Mtoe)	30.42
Electricity consumption (TWh)	64.31
Carbon dioxide emissions (Mt of CO_2)	97.81
TPES/population (toe/capita)	2.71

2.1. Climate

Greece is located between latitudes 34° and 48° in the Northern Hemisphere, experiencing typical Mediterranean climate with relatively warm and dry summers, mild and rainy winters and generally long sunshine periods throughout the year. In Greece the climatic condition varies mainly due to the topographic configuration and extended alternation between the land and sea. The cold and rainy season lasts from mid-October to end of March and the hot and dry season from April to October. The average minimum temperature ranges from 5 to 10 °C in coastal areas and from 0 to 5 °C in inland areas. The winter is milder in the Aegean and Ionian sea regions than in northern and eastern Greece. The warmest period is within July and early August when the mean maximum temperature ranges from 29 °C to 35 °C [5,6].

2.2. Energy status and GHG emissions

2.2.1. Electrical energy

Electricity can be generated using fossil fuels and renewable energy resources. The mix of energy generation technologies depends on factors such as available local energy resource, international circumstances, local energy policy and geological, geophysical, geographical and climatic features.

In EU-27, the production of electricity from new RES (other than hydropower) was estimated to be 198 TWh in 2007. With the hydro production remaining relatively constant, a significant growth in new RES was observed in the past three decades. Wind power is the main cause of this growth, growing from almost zero in 1990 to 100 TWh of production in 2007. In terms of fossil fuel fired power production, coal and lignite were used for the production of more than half of the generation with 930 TWh in 2007 whereas 6% was produced by oil fired units and a significant 42% by gas-fired units [7].

The installed energy generating capacity in Greece during the period between 1990 and 2007 is shown in Fig. 1. Vastly available lignite is the main energy resource in Greece. The oil based power generation plants also contribute significantly in Greece. It can be seen from Fig. 1 that there is a fixed share of installed hydropower units, a gradual increase in natural gas power generation plants and a small but continuous increase of installed wind power plants signifying a new era for the penetration of renewable resources in Greece.

Fig. 2 shows the electricity production in Greece for the period between 1990 and 2007. The total power generation has gradually increased over the period and the annual percentage share of lignite and oil power sources has declined (see Fig. 2). The annual share of power production from natural gas, wind and other renewable resources has steadily increased over this period.

Table 2 presents a comparison between EU-27 and Greece in terms of energy production and usages. The size of the Greek energy market represents a share of less than 2% of the EU market. Table 2 indicates that a significant effort is required by the Greek

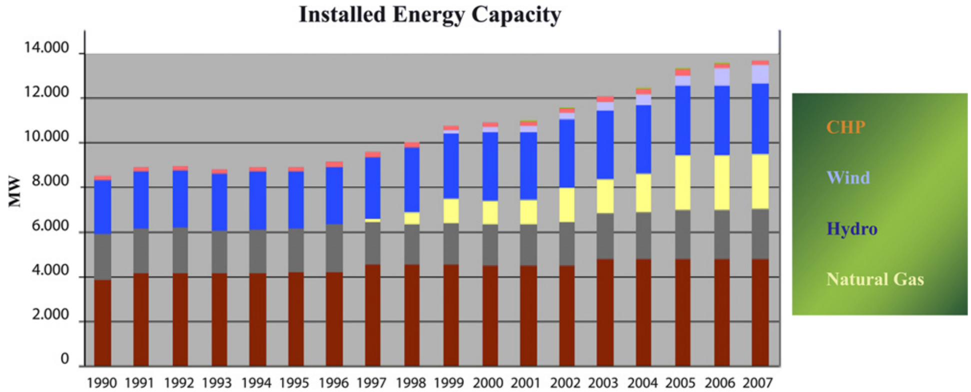

Fig. 1. Installed energy production capacity in Greece (1990–2007) [8].

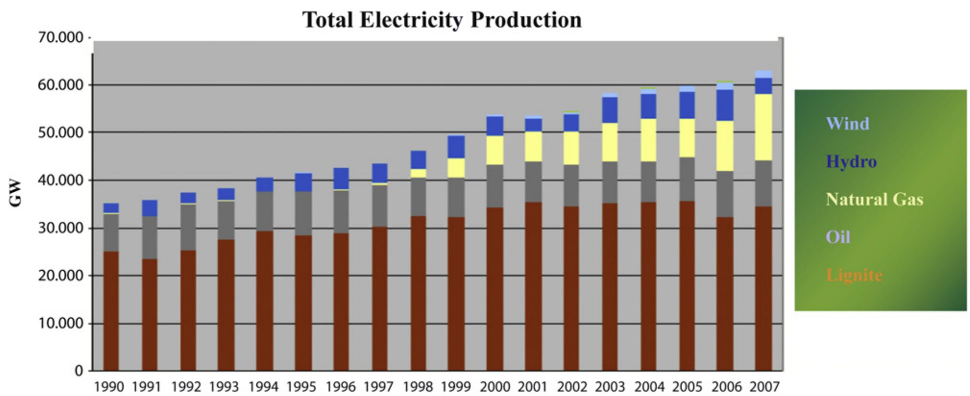

Fig. 2. Total electricity production in Greece (1990–2007) [8].

Table 2
Comparison of key energy figures between EU-27 and Greece [9].

Final energy consumption of electricity (1000 t of oil equivalent) EU (27)		
	1999	2010
EU-27	210,491	243,907
Greece	3492	4576
Total gross electricity generation—GW h		
	1999	2010
EU-27	2,941,947	3,345,618
Greece	49,632	57,392
Electricity generated from renewable sources (% of gross electricity consumption)		
	1990	2010
EU-27	11.62	19.94
Greece	4.96	16.68
Electricity consumption of households (1000 t of oil equivalent)		
	1990	2010
EU-27	52,022	72,456
Greece	780	1559

government to increase the electricity generation from renewables as it is still below the average share of EU-27.

2.2.2. Overview of power and GHG emissions

In Europe, the public electricity and heat production contribute 30% of the total GHG emissions. If the infrastructure of electricity and heat production had been unchanged over the period 1990–2007, the CO_2 emissions would have increased by 32% above 1990 levels. However, this is not the case, and this is because there was a 13% reduction in the fossil-fuel input/unit of electricity produced from fossil fuels mainly due to the installation of energy efficient new power plant and another reason is the fossil fuel switching [10].

In 2010, the EU-27 GHG emissions increased by 2.4 % compared to 2009 and are estimated to be 4721 Mt of CO_2 eq. The total GHG emissions decreased by 15.4 % (862 Mt CO_2-eq.) between 1990 and 2010. Over the same period, the emissions decreased in Lithuania by 58%, Latvia 55%, and Romania 52% whereas the emissions increased in Germany (+24.7 Mt of CO_2 eq.), United Kingdom (+19.7 Mt of CO_2 eq.) and Poland (+19.1 Mt CO_2 eq.) accounting for more than half of the total EU-27 net increase. On the other side, Spain (−10 Mt CO_2 eq.), Greece (−6 Mt CO_2 eq.) and Portugal (−4 Mt CO_2 eq.) are the countries with the higher emission reductions in 2010 and one reason for this could be the economic recession [11].

An impressive 250% growth rate in RES capacity and 13% growth in fossil fuel fired power plant were observed between 2000 and 2007. However, the fossil fuel is still the main resource for power generation in Europe. The shares of coal and lignite power capacity constitute half of the current total of 442 GW of fossil fuel fired capacity in EU-27 [12].

Within the period from 1990 to 2008, the energy efficiency in the residential sector improved by 19% in EU-27 with an average rate of 1.1%/year. During the same period, the final energy consumption in the residential buildings increased by about 13% with an annual average rate of 0.7%. The household energy consumption/capita in EU-27 over the same period increased slightly; however, since 2005, the energy consumption/capita in the household sector decreases slightly.

Particularly, in the southern European countries like Greece, the reduction in residential energy consumption was remarkably rapid because of increasing comfort levels. Over the period 2005–2007, the final residential energy consumption/capita decreased

almost everywhere, except in Finland, Estonia, Poland and Spain. The rate of decrease was 4.1%/year for the EU-27. In 2008, the residential energy consumption increased by 3.8%, except in 3 countries namely Italy, Portugal and Greece (−3.9%) where the consumption/capita decreasing steadily. Within the period from 1990 to 2008, the residential electricity consumption/capita in the EU-27 went up by 32% with an average annual growth rate of 1.6%.

Despite the increase of the residential buildings and electrical appliances over the period from 1990 to 2007, the total CO_2 emissions/dwelling decreased by almost 24% in the EU-27. This decrease was mainly driven by the use of biomass fuel and RES electricity. The total CO_2 emissions/m^2 for space heating decreased by an average of 2.3%/year in the EU-27 between 1990 and 2008. It is estimated that the total emissions/m^2 of Norway, Finland and Latvia are more than five times lower than that of Greece [12].

Fig. 3 illustrates the installed power plant capacity during the period from 1953 to 2007. The per capita annual electricity consumption has increased from 88 kW h to 4970 kW h over the last 60 years (see Fig. 4).

Coal is the main primary energy source for heating and electricity production in Greece. The usages of natural gas and wind power are increasing rapidly, as well. The hydropower depends on the climates and rainfalls. Table 3 shows the electricity and heat generation by sources. The total final energy consumption has increased by 57.2% over the last decade. The main energy and environmental figures over the period from 1998 to 2010 are shown in Table 4. Table 5 gives the current energy balance in Greece [14]. Over the period from 1980 to 2007 the GHG emission increased by 100% (see Fig. 5). In 2008, the energy related emission was 82.0% of the total GHG emissions which is 34.1% higher than that in the base year. The average annual increase rate of CO_2 emission was 1.8% during the period from 1990 to 2008. The power generation plants contributed 55.5% of the total GHG emissions over the period from 1980 to 2007.

The fossil fuel use in household sector increased by 100% between 1990 and 2007 and for heating only, the growth rate reached about 104%. The high growth rate was due to improvement in the quality of life [18]. GHG emissions in the residential sector are increasing rapidly mainly due to integration of gaseous fuels into the energy mix and inefficient combustion technologies used for burning fuels. GHG emissions from biomass and solid fuels are gradually decreasing mostly due to improvement in combustion related technologies. Table 6 shows GHG emissions in the residential sector from 1990 to 2008 [8].

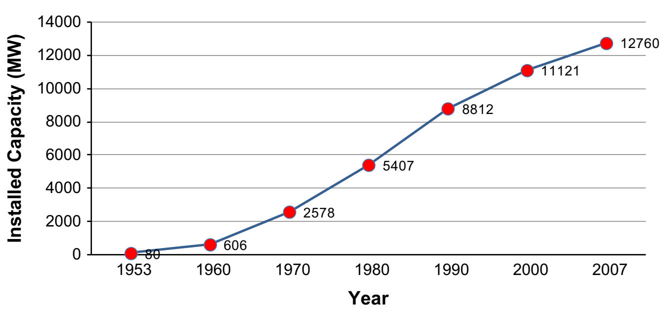

Fig. 3. Installed capacity in Greece (1953–2007) [13].

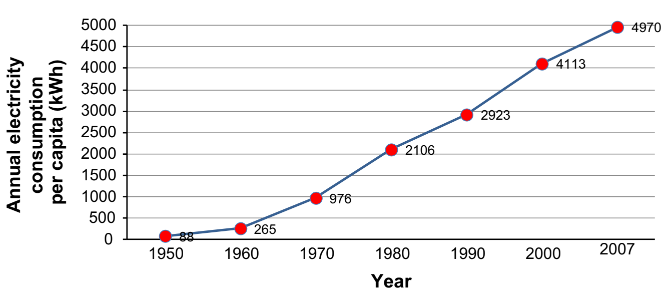

Fig. 4. Annual electricity consumption per capita in Greece (1950–2007) [13].

Table 3
Electricity/heat production in Greece in 2009 [15].

Production from	Electricity (GW h)	Heat (TJ)
Coal	34,188	2023
Oil	7679	27
Gas	11,023	0
Biofuel	218	0
Hydro	5645	0
Solar PV	50	0
Wind	2543	0
Total	61,365	2050

Table 4
Key energy and environmental figures in Greece (period 1998–2010) [16].

	1998	2010
Total primary energy production	10,039 ktoe	9456 ktoe
Primary energy production from lignite	8353 ktoe	7315 ktoe
Total primary production from RES	1329 ktoe	1985 ktoe
Solar power	94 ktoe	197 ktoe
Biomass and wastes	908 ktoe	887 ktoe
Hydro	320 ktoe	641 ktoe
Wind	6 ktoe	233 ktoe
Net imports of primary energy	21,179 ktoe	31,649 ktoe
Final energy consumption	18,201 ktoe	19,027 ktoe
Energy dependency	69%	69.11%
Total gross electricity generation	46,332 GW h	57,392 GW h
by hydro	3866 GW h	4149 GW h
by wind	73 GW h	2242 GW h
Electricity consumption of households	1068 ktoe	1559 ktoe
Emissions		
Total GHG emissions	118 Mt CO_{2eq}	118 Mt CO_{2eq}
Per capita emissions in the residential sector in 2010	2039 kg CO_2/capita	
Total CO_2 emissions	103 Mt CO_{2eq}	110 Mt CO_{2eq}
CO_2 emissions/kW h from electricity and heat generation	736 gCO_2/kW h	
By using oil	753 g CO_2/kW h	
By using coal/peat	975 g CO_2/kW h	

Table 5
Energy balance of Greece and EU-27 [14,17].

	Ktoe				
	TPES	Industry	Transport	Residential	Agriculture
Coal/peat	8321	390	0	6	0
Oil	20,188	0	0	2555	802
Gas	3505	453	21	207	0
Hydro	285	0	0	0	0
Solar/geothermal	383	0	0	177	7
Combustible RES	1049	264	69	664	15
Electricity	483	1332	21	1559	267
Heat	0	0	0	44	0
Total	30,419	4206	7526	5212	1091
Total EU 27	1,655,793	254,961	322,267	294,874	294,874

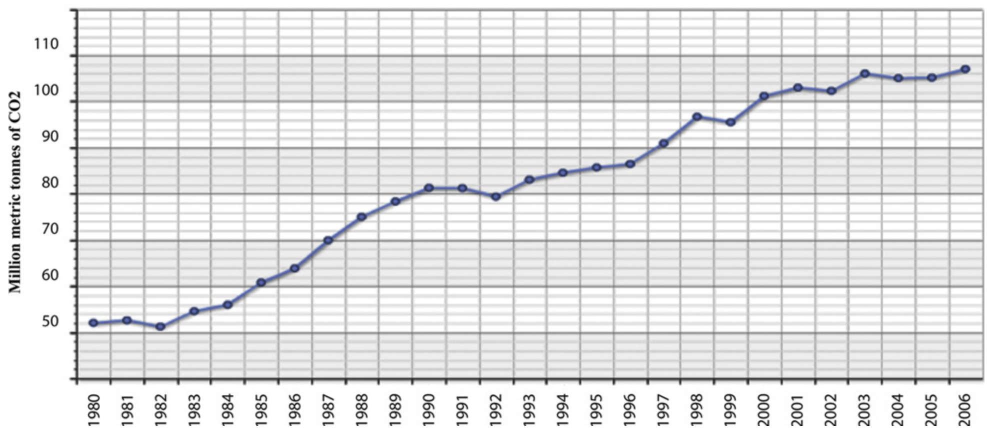

Fig. 5. GHG emissions trend over the period from 1980 to 2007 [14].

Table 6
GHG emissions (kt of CO_{2eq}) in the residential sector from 1990 to 2008 [8].

GHG emissions in the residential sector (kt of CO_{2eq})	1990	2000	2008
CO_2			
Solid fuels	81.71	69.86	23.68
Liquid fuels	4584.82	7494.44	7880.55
Gaseous fuels	4.92	11.15	479.18
CH_4			
Solid fuels	0.02	0.02	0.01
Liquid fuels	3.76	6.35	6.70
Gaseous fuels	0.01	0.00	0.18
Biomass	76.59	90.20	63.52
N_2O			
Solid fuels	0.40	0.35	0.11
Liquid fuels	10.45	18.65	19.72
Gaseous fuels	0.04	0.07	0.27
Biomass	31.80	37.45	26.37

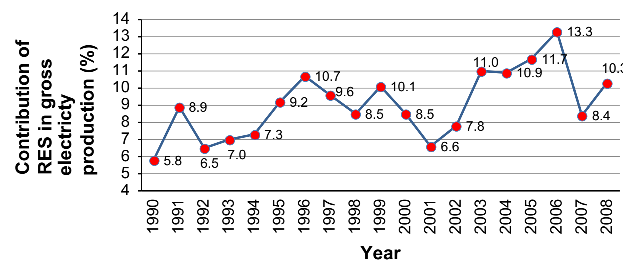

Fig. 6. Contribution of RES in gross electricity consumption [16].

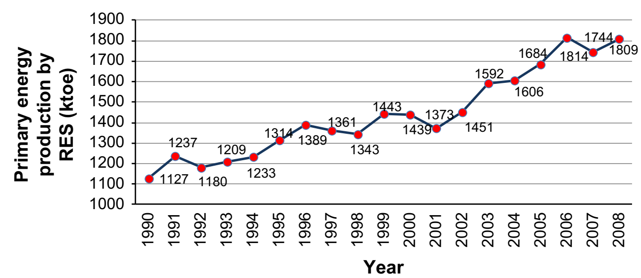

Fig. 7. Primary energy production (ktoe) by RES (1990–2008) [16].

3. Renewable energy sources

3.1. Current status

In 2010, the renewable energy production within the EU-27 was about 166 Mtoe, approximately 20.1% of the total primary energy production. The average annual increase rate of renewable energy production was 5.6% between 2000 and 2010. The largest renewable energy producer within EU-27 in 2010 was Germany with a 19.6% share of the total followed by France (12.5%) and Sweden (10.4%). In terms of gross energy consumption, the RES accounted for 8.7% of the total in the EU-27 in 2010. Among the Member States, Sweden presented the highest share (47.9%) of renewables in gross final energy consumption in 2010 followed by Latvia (34.5%), Austria (25.6%) and Portugal (19.7%). In EU-27, the electrical power generation from RES accounted for almost one-fifth of the gross electricity consumption. Austria (61.4%), Sweden (54.5%) and Portugal (50.0%) are the leading countries in terms of the electrical power generation by RES. The growth in electricity generation from RES is mainly due to rapid expansion of wind turbines and biomass while hydropower remained the largest source for renewable electricity generation in the EU-27 in 2010 [19].

In Greece, the climatic conditions and topography are ideal for renewable power generation. During 1990–2008 the growth of solar energy production was 47%. The RES contributes 5.6% of the total gross domestic consumption and approximately 17.7% of the domestic production of primary energy. The production of primary energy from RES, in 2008, reached about 1.6 Mtoe, while in the early 90s it was only about 1.2 Mtoe. In terms of production, 865 ktoe is due to biomass use in the households and industries (53.0%), 285 ktoe (17.4%) came from hydro plants, 193 ktoe (11.8%) from wind power, 174 ktoe (10.6%) due to solar thermal power systems, 63 ktoe (3.9%) from biofuels, 35 ktoe (2.2%) from biogas and finally 17 ktoe (1.1%) from geothermal power plants [20]. Fig. 6 shows the contribution of RES in gross electricity consumption.

Fig. 7 shows the trends of primary energy production in terms of ktoe by RES during the period from 1990 to 2008.

In Greece, the wind power generation potential is enormous particularly the islands of the Aegean Sea are the most favorable sites for wind resource with average wind speed of 62–88 km/h. Wind power generation has significant impact on sustainable development, energy saving, environmental protection and climate change issues [21–23].

Biomass also plays a key role in the energy production contributing to heating, cooling and electricity generation. A recent report suggests that approximately 450,000 toe of firewood

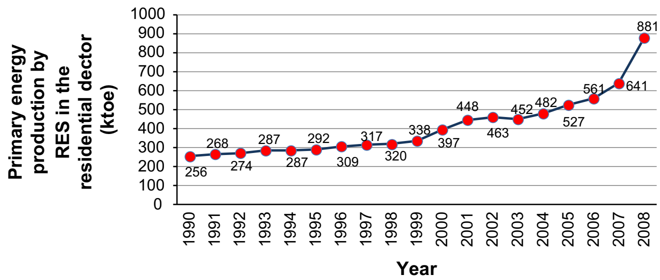

Fig. 8. Primary energy production (ktoe) by renewable energy resources (RES) in the residential sector (excluding large hydro and biomass) [16].

is used for heating purpose covering up to 2% of the total energy demands of the country [24]. The increase in biomass use is the main driver for the growth of 144% in RES in Greece during the period from 1990 to 2008 [25]. The available biomass resource from agricultural and forestry residues per year in Greece is equivalent to 30–40% of the total oil consumption in the country [26]. Despite this, in Greece today, only 3% of the total energy requirement is covered by biomass used mainly for residential heating purpose. The total available biomass in Greece is estimated to be 7.5 Mt from crops and 2.7 Mt from forest residues. Fig. 8 illustrates the primary energy production by RES at a domestic scale, during the period from 1990 to 2008 excluding biomass and hydro energy resources.

Greece has excellent solar energy resource. The average annual solar radiation is estimated to be 1570 kW h/m^2. In major parts of the country, the sun shine hours are more than 2700 h/year, or 7.5 h/day, while in areas like southern Aegean, the hours of sunshine are 3100/year or 8.5 h/day. High solar resource can be used for heating and electricity production in the country. More than 50,000 of solar hot water systems (SWHS) are installed every year in the households with the total number close to one million [27].

3.2. Barriers

The main barriers of RES implementation into the European energy mix are lack of legal framework for independent power producers, the complexity in the fuel price risk assessment, the transaction costs, restrictions on sitting and construction, the subsidies for competing fuels, the high initial capital costs, the environmental externalities, the utility interconnection requirements and the insufficient spatial planning [28].

In Greece, the target is to generate 20% of the electricity from renewable resources by 2020 [20]. The energy consumption increased by 10 times over the period from 1975 to 2005 implying an exponential annual growth rate of 10% [29]. The main barriers in achieving this target are misguided interventions related to spatial planning for RES, lack of involvement of the local communities and authorities in the spatial planning procedure, lack of awareness of citizens on relevant issues, non-existent legal framework relevant to the specifications of the facilities and finally high electrical transmission losses. The main technological barriers for the RES implementation in Greece are poor grid infrastructure and lack of detailed data illustrating the RE potential of each zone of the country. The other barriers include lack of clear national strategies to evaluate the impacts of the RES projects, lack of financial advantages to support RES investments and lack of a national policy on planning for RES installation and lack of promotion for the RES.

3.3. Action plan

The immediate priorities of action plan to improve renewable energy share must be divided into two phases. In the first phase the energy savings measures should be introduced in day to day life through the enactment of relevant legislative instruments and by providing appropriate tax incentives. In the second phase, additional grants and incentives should be adopted especially in the lower social strata. Along with this new management structures and policies action planning groups must be developed for the implementation of more innovative legislative initiatives [30].

4. The building sector in Greece

The building sector is responsible for about 40% of the total final energy demand at the national level, contributing significant GHG emissions. The heating demand in buildings accounts for 70% of the total energy consumption. The potential energy savings can be achieved in buildings by using appropriate techniques and cost effective technologies and improving energy efficiency. Fig. 9 illustrates the building stock in Greece in terms of construction period. The buildings built before 1980 account for 74.6% of the total building stock. These buildings are poorly insulated and use low efficient heating and air-conditioning units [31].

According to the Hellenic Statistical Authority, in 2006, 71% of the buildings were constructed before 1980 and 77% of these are residential buildings. The average annual growth rate of energy consumption in buildings over the period from 1985 to 2005 was 4.5% and 3% with respect to the total energy. More specifically, in 2005, the buildings' energy consumption was 85,923 GW h of which 63,407 GW h was consumed by households [32].

The energy demand in the domestic building is mainly due to space heating (57%), hot water requirement (22%) and lighting (9%). The energy savings in buildings can be achieved mainly by improving thermal insulations of building fabrics, use of double glazing and installation of biomass boilers. The overall savings could be up to 16 TWh by 2016 with 60% via improving thermal insulation, 2 TWh due to installation of SWH systems and 0.5 TWh due to the replacement of incandescent bulbs with fluorescent lighting. Finally, significant savings could be achieved by using more efficient technologies in household [30].

4.1. Regulation on the energy performance of buildings in Greece

Buildings regulation is applied to improve energy efficiency in buildings, energy savings and environmental protection through specified action including the study of building energy performance, the establishment of minimum building energy efficiency standard, the building energy rating and the energy auditing of buildings. The benefits of this regulation are environmental and socio-economic, once the emissions and fuel consumptions are reduced and the number of relevant jobs is increased [8].

4.1.1. Energy rating categories

The classification of buildings is based on estimated total energy consumption in kW h/m^2. In Table 7, R_P represents the estimated primary energy consumption of the reference building and the term T presents the ratio of the estimated primary energy

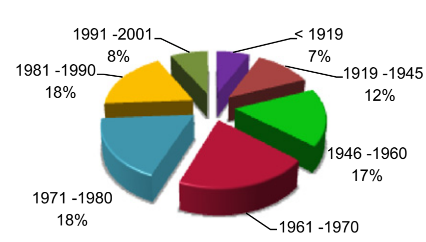

Fig. 9. Share of buildings built per period [31].

consumption of the examined building (*EP*) to the estimated primary energy consumption of the reference building.

4.1.2. Minimum energy requirements

All buildings should meet minimum *U*-value standard for insulation. All new and substantially renovated buildings must have energy efficiency of category B or less. A detailed picture of the thermal transmittances of the main building components is summarized in Table 8 [33]. Also, the average thermal transmittance rate of the exterior surface walls, including doors and windows, should not exceed 1.86 W/m^2 K/floor.

5. Energy policies and legislation

5.1. General targets and strategies

The main strategies and energy policies implemented by the member states of EU-27 include electricity feed-in laws, renewable energy (Green) certificates, subsidies and rebates, tax relief policies, accelerated depreciation, production tax credits, property tax incentives, personal income tax incentives, sales tax incentives, pollution tax exemptions grants, loans and infrastructure policies, equipment standards and contractor certifications, emissions cap-and-trade policies, GHG mitigation policies and others [34].

In Greece, the energy policy is focused on the expansion of RES especially in the island region where the wind and solar energy potentials are high [35–38]. Greece has an obligation to keep the increase in GHG emissions rate below 25% compared with 1990, by 2012. The total allowed CO_2 emission from thermal power plants is restricted to 41,739,165 t CO_2/year during the period from 2008 to 2012 [39,40]. According to the European guidelines, the emissions must be reduced linearly from the middle of the period from 2008 to 2012. This amount should be reduced by a linear rate of 1.74% compared to average annual total quantity of emission. The CO_2 emissions should not exceed 10% compared to the base year 1990 by the year 2020 [41] corresponding to a decrease of 1.5%/year. In order to reach the target, the CO_2 emissions in year 2020 are estimated to be 36,730,465 t.

The main target of the Greek energy policy is to discover, secure and manage energy resources to ensure safe, smooth, seamless and reliable coverage of the energy needs in the country. The second objective is to create energy resources, alliances and alternative routes to meet the needs of the domestic energy market. The third goal is to develop viable and sustainable energy sector [42].

The strategy for meeting energy demand and addressing the energy issues in Greece is achieved by introducing necessary regulatory and legal framework focusing on the guidelines as follows:

- possible use of various energy sources;
- build pipelines for oil and natural gas in international networks;
- increased use of indigenous energy resources and reserves;
- independence from imported energy;
- development of renewable energy facilities and incentives;
- use and dissemination of clean and efficient technologies that are environmentally friendly;
- liberalization, expansion of competitiveness, elimination of monopolies in the electricity and gas sectors;
- create a positive investment climate for private companies in the production and supply of electricity sectors;
- save energy in industry, transport, buildings and dwellings;
- set national target to increase the penetration of energy produced from renewable sources, reducing greenhouse gas emissions and saving energy [42].

With the Directive 2002/91/EC of the European Parliament, a series of measures targeting to improve the energy behavior of buildings and increase in efficiency of heating and cooling systems has been introduced. The main points of the Directive are [43]

- establish minimum standards on the energy performance of new buildings and existing buildings that are being renovated;
- introduce frameworks for the energy certification of new and existing buildings;
- establish a common methodology for estimating the integrated energy performance of buildings;
- establish an inspection procedure for the operation of boilers and central air-conditioning systems in buildings.

Deep interventions in the Greek electricity market were introduced by the Acts 2773/1999 and 3426/2005 and are summarized as follows:

- liberalization of the electricity and setting of energy policy plans;

Table 7
Energy classification system [33].

Category	Category's limits	Category's limits
A$^+$	$EP \le 0.33R_P$	$T \le 0.33$
A	$0.33R_P < EP \le 0.50R_P$	$0.33 < T \le 0.50$
B$^+$	$0.50R_P < EP \le 0.75R_P$	$0.33 < T \le 0.50$
B	$0.75R_P < EP \le 1.0R_P$	$0.33 < T \le 0.50$
C	$1.0R_P < EP \le 1.41R_P$	$0.33 < T \le 0.50$
D	$1.41R_P < EP \le 1.82R_P$	$0.33 < T \le 0.50$
E	$1.82R_P < EP \le 2.27R_P$	$0.33 < T \le 0.50$
F	$2.27R_P < EP \le 2.73R_P$	$0.33 < T \le 0.50$
G	$2.73R_P \le EP$	$2.73 \le T$

Table 8
Thermal transmittance of building components for different climate zones [33].

Components	Thermal transmittance (W/m^2 K)			
	Climate zone			
	A	B	C	D
External horizontal surfaces in contact with the outside air (roofs)	0.5	0.4	0.4	0.3
External walls in contact with outside air	0.7	0.6	0.5	0.4
Floors in contact with external air	0.5	0.4	0.4	0.3
Floors in contact with ground or with heated spaces	1.5	1.0	0.7	0.5
Interior walls in contact with non-heated spaces	1.5	1.0	0.7	0.5
Openings (windows, balcony doors etc.)	3.2	3.0	2.8	2.6
Glass facades (able to open or able to partially open)	1.4	1.4	1.4	1.4

- power generation activities were set under the supervision of state;
- establishment of an independent administrative body (Regular Authority for Energy) with its main responsibility being the supervising, monitoring and controlling, the proper functioning of the energy market. If market failure occurs, RAE may intervene in the market and propose measures, to restore compliance with the rules of competition, for the customer's protection.

The Greek government has adopted specific environmental and development policies established by the European community [44–46]. The national target for the renewable energy contribution in final energy consumption has been increased to 20%, or more specifically, 40% of electricity generation, 20% of heating and cooling needs and 10% of energy consumption in transport from RES. Additionally, in relation to energy savings, Greece has already established the first energy efficiency action plan, where according to Directive 2006/32/EC about 9% energy savings is provided in final energy consumption by 2016, while recently the law 3855/2010, which was added to the recent regulation on energy performance of buildings, proceeds toward the development of market mechanisms and toward the implementation of specific measures and policies, specially designed to achieve the national target for energy savings [20].

The first historical, legislative interventions in Greece were made by the laws L1559/1985 and L2244/1994. The law L1559/1985 on the "Regulation of issues of alternative forms of energy and specific issues of power production from conventional fuels and other provisions" was the first legislative attempt to consider new forms of power for electricity and heating production, and established the first exceptions to the right of PPC to produce energy by using conventional fuels only in a monopolistic manner [47].

The main barriers for the significant development of large scale RES plants in Greece arise mainly due to bureaucratic constraints, social opposition of the local communities, improper grid structure, lengthy and cumbersome licensing procedures and deficiencies in the national spatial planning. That is why, the law L3851/2010 tried to address some of these issues, mainly the social opposition, by introducing a 3% tax before VAT to the gross revenues from electrical power sales produced by RES (except PVs), which will be attributed to the local authorities for development purposes.

In terms of small scale decentralized domestic installations a license called "small works permit" is required from the local urban planning office for the installation of solar thermal systems. The same permit is required for the PV system with capacity up to 10 kW with additional benefit from high rated feed-in tariff. It is a tax free procedure excluding 23% VAT on the initial equipment cost. To be eligible for this scheme, the only obligation for the owner is that the building should cover part of its hot water demand by some other RES, for example, a SWH system. Then after requesting the local PPC branch, the company prepares the contract which provides the compensation through the quarterly energy bill and takes care of any additional installation work needed, including installation of appropriate meter. Recently, the installation process for small wind turbines, SWH systems and small scale PVs in the residential sector was made very simple without the requirement for "small works permit" and by a simple notification to local urban planning authorities. The law L3851/2010 states that all new buildings should cover their needs completely by renewable energy technologies and CHP by 31 Dec, 2019. [27]

5.2. General framework

The significant development of RES in Greece began in the 90s, with the massive implementation of solar thermal systems in the households. This first attempt to integrate renewable energy technologies in the households was supported by the law 2364/95 which established a 75% tax deduction of the total expenditure on the purchase and installation of residential RES appliances. Unfortunately, this deduction was suspended in 2002 by the law L3091/2002. Law 2244/1994 "on electricity from renewables" played a very significant role for large-scale RES development in the country. The interest in investing in renewable technologies increased mainly due to high renewable energy potential and high feed-in tariffs and subsidies.

Until 2006, the RES development was mainly focused on wind power and solar thermal systems. At that time, the new feed-in tariffs were introduced within the law L3468/2006. The previous scheme set by L2244/1994 was modified by introducing different tariffs for different technologies, offering significant increase in tariffs for solar power and offshore wind systems. The PV system growth was significant during the period from 2006 to 2009 because the cost of PV systems dropped due to technological development. The PV feed in tariff was reduced since June 2010.

5.3. Regulations

The use of renewable energy is not mandatory in Greek legislation. However, the European Commission has set a target for renewable energy generation that influences Greek legislation. The target of 20.1% of RES share in the gross electricity consumption by 2010 was set by the Directive 2001/77/EC. A few years later, in the European Directive 28/2009, the target of RES share in the gross electricity consumption was further increased. This target was extended unilaterally by the Greek government to 29% of the total electricity consumption.

In Greece, the "National Development Law" was introduced to provide subsidies for supporting RES projects. The law covers the activities in all economic sectors in every region of the country particularly the regions with low GDP per capita and high unemployment rates where the subsidy rates are higher compared to other more developed regions of the country. The eligible funding categories under this law include power generation from wind, solar, hydroelectric, biomass and geothermal plants, the electricity and heat cogeneration and finally the waste disposal projects. A tax deduction of 205% in residential off-grid RES systems was introduced in the National Development Law with the target to support further small scale renewable technologies in the residential sector.

5.4. Feed-in tariffs

In Greece, the feed in tariffs were institutionalized by the law L2244/1994 and were modified by the laws L2773/1999, L3468/2006, L3734/2009 and L3851/2010. Under the law L2244/1994 fixed sale prices were established for the renewable power generation systems. For the interconnected systems, the price was set at 0.07287 €/KW h and for the autonomous-grid islands the pricing was fixed at 0.08458 €/KW h. The feed in tariff is guaranteed for 12 years with a possible extension up to 20 years. Fig. 10 shows the feed-in-tariffs for different renewable energy technologies as recently established by the law L3851/2010.

6. Overview of Aegean Sea Islands

6.1. General information and energy issues

The Aegean Sea islands can be categorized into three main clusters of islands. The Cyclades consisted of 220 islands in the south-eastern part of the country with an area of 2572 km^2 and

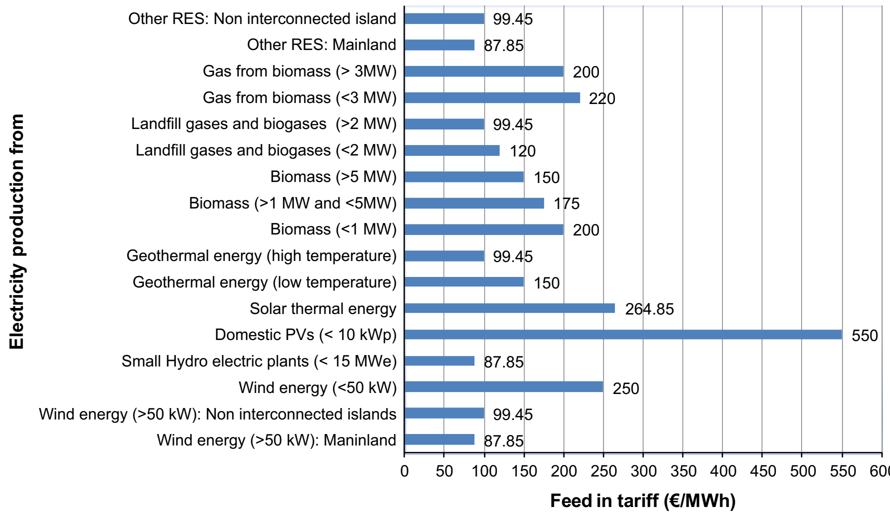

Fig. 10. Feed in tariffs for different renewable energy technologies [48].

population of 119,549 (based on 2005 data). The second one, Dodecanese, consisted of 12 major and 150 small islands located in the south-eastern part of the Aegean Sea with area 2714 km^2 and population of 200,452. The third part is in the north of the Aegean Sea.

The national target of 20% electricity generation from RES by 2020 would not be achieved unless there is an extensive reliance on wind energy particularly in the islands with greatest potential. At the present time 8000–10000 MW renewable generation is required to achieve this target, but in 2008 the total installed capacity was below 900 MW with only 71 MW installed in the Aegean Sea islands. The failure in achieving this target was mainly due to lack of investment, insufficient grid structure and the negative reactions of the local people.

As energy is at the heart of the philosophy of sustainable development and energy choices affect all aspects of social and economic activity, the usual practice for energy use must be changed. In islands, the fossil fuels use creates environmental, economic and social problems, while the location and morphological characteristics of the islands do not allow easy integration of the continental power grids. Thus, the diffusion of renewable energy and implementation of sustainable energy solutions are emerging as the top priority to meet the energy needs of the islands, to provide energy security, to allow primary energy saving and to protect the environment. The energy related problems in islands include high fossil fuel dependence, high cost of conventional power, significant problem in electrical power supply, insufficient base load due to lack of large industrial plants, high yearly growth rate of energy demand and significant seasonal variations of load demand mainly due to tourism market.

These islands have high-unused-RES potential and substantial room for energy savings. The Energy Planning that includes recording current energy profile, considering actual energy potential, exploring appropriate technologies, identifying social and environmental problems, addressing institutional barriers and examining options for funding projects is one of the key processes for the implementation of renewable technologies. Apart from the technical-barriers, the policy and legislation, the penetration of renewables and energy saving techniques in a society is largely determined by their social acceptance. Greece has fallen behind the European countries in issues relevant to renewables and energy saving, although people living in Greece are very sensitive to environmental issues. One reason contributing to this situation is the lack of social acceptance, especially for the large-scale renewable electricity generation such as wind farms. In many islands, especially in Aegean, the installation of renewable energy power plants encounters negative reactions from the local authorities, social groups and social organizations [13,49–52].

6.2. *Renewable energy potential, barriers and energy saving*

6.2.1. *Renewable energy potential*

The investment opportunities in the renewable energy sector in islands are growing mainly due to available renewable energy resources [53]. Moreover, socio-economic benefits could accrue by introducing appropriate strategies in relation to optimization of energy mix and supply of electricity to the islands, especially those with water scarcity [54]. Because of the high renewable energy potential in the Aegean Sea, the proper introduction and application of innovative technologies could cover up to 100% of local energy needs [55,56]. Several studies have been conducted on the implementation of various renewable energy technologies for buildings in large islands [57–61]. Optimum use of hybrid systems in the islands could lead to power coverage of about 85–90% [62–64].

6.2.1.1. Wind and solar energy potential. The wind and solar energy potentials in Aegean Sea were recorded for several islands and sub-regions and are presented in Table 9 and Fig. 11, respectively.

6.3. *Energy efficiency*

The energy efficiency measures in buildings have significant importance in the islands. The building sector accounts for approximately 46% of total final energy consumption. However, the implementation of energy efficiency measures in buildings requires a special approach because of the architectural constraints, compact constructions and special weather conditions. The energy efficiency measures in the poorly insulated old buildings could significantly improve their economic performance and reduce CO_2 emissions. The most important energy efficiency measures include the replacement of the old air-conditioning devices and heating boilers, the regular inspection of the new boilers, the enhancement of external wall insulation, the sealing of leakages and the use of roof ventilators and use of low-energy light bulbs [66]. Figs. 12 and 13 summarize the electrical power requirement and status in the Aegean Sea islands.

Table 9
Wind energy potential [65].

Region		> 6 m/s	> 7 m/s	> 8 m/s	> 9 m/s	> 10 m/s
North Aegean	Average speed (m/s)		6.5	7.7	9.2	10.8
	Potential (MW)		6592.8	2452.8	871.2	346.4
South Aegean	Average speed (m/s)	6.6	8.9	9.8	10.7	11.8
	Potential (MW)	346.4	17,712.1	11,073.3	6161.9	3469.9
Crete	Average speed (m/s)		9.1	10.1	10.9	11.5
	Potential (MW)		1897.6	1192.0	742.4	513.6
Total	Average speed (m/s)	6.5	8.2	9.4	10.6	11.6
	Potential (MW)	28,322	41,709	20,570	10,535	5859

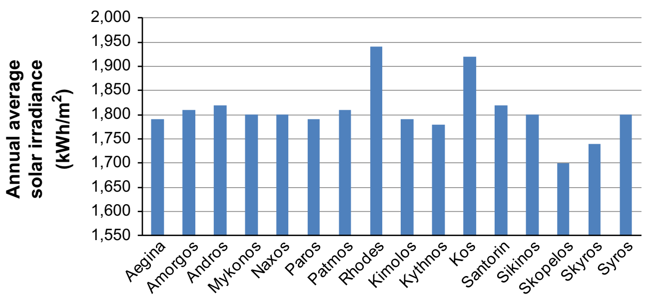

Fig. 11. Annual average solar irradiation under optimum angle (kW h/m^2) in major Greek islands [65].

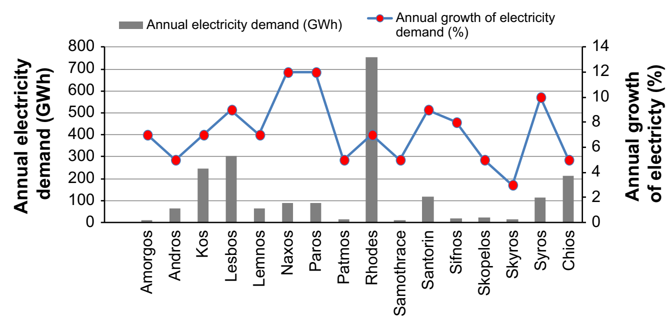

Fig. 13. Annual electricity demand (GW h), in major Greek islands [65].

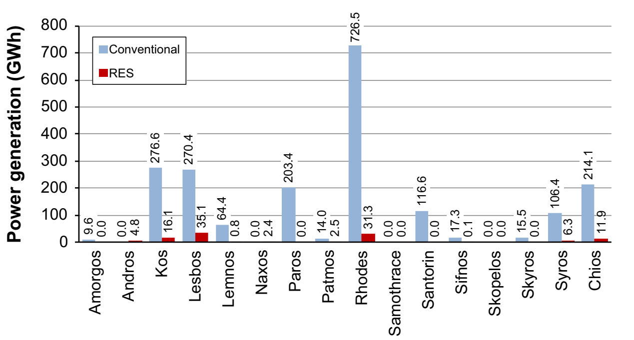

Fig. 12. Power generation (GW h) by fossil fuels and RES, in major Greek islands [65].

6.4. Prospects in the residential sector

6.4.1. General

The energy-saving interventions are usually more efficient in old, energy-intensive buildings. The two main factors affecting the energy performance of a building are the active systems and the thermal transmittance of the building envelope. In Greece, 82% of the buildings were built before 1980. The energy efficiencies of these buildings are very poor and thus they have a great potential for energy savings through energy efficiency measures. In Greece, the islands with the greater potential for energy savings in existing buildings are Lesbos, Kimolos, Sifnos, Lemnos, Chios, Nisyros, Samothrace, Andros and Patmos.

The "Hellenic General Building Code" is the most important legislation in relation to building construction [67] containing the basic conditions, requirements and restrictions for constructions inside or outside the spatial plan of town [68]. The "Thermal Insulation code" came in 1979 to cover the energy and environmental considerations into building constructions in Greece. According to this Code, Greece was divided into four zones based on climates. The code determines precisely the maximum average heat transmission rate of the buildings for each of these climate zones ranging from 0.616 to 1.553 W/m^2 K [49].

Every zone presents different climatic conditions varying from mild climatic conditions to the cold north zone. The Aegean Sea islands belong to the milder regions. The number of heating degree days in a particular geographic region signifies the thermal energy demand for the buildings. Table 10 shows the islands categorized based on degree days. The islands in higher latitudes tend to have higher value of heating degree days.

For each climatic zone different subsidy rates are in place for the support for new technologies. For Zone A (Cyclades, Dodecanese, Sporades, Crete) and Zone B (North Aegean islands) the subsidy rates are 30% and 40%, respectively [65]. Table 11 shows the energy production cost for Greek islands.

The age of the buildings is an important factor particularly the relative percentage share of the old buildings to the total building network of the islands. The relative percentages are categorized into very high to low. The Islands within each category are shown in Table 12.

A combination of the obtained findings above may result in an overall classification for each island in terms of potential energy savings in the residential sector as shown in Table 13.

7. Conclusions

In Greece, the installed capacity of power plants increased by 12,860 MW (15.850%) during the period 1953–2007. In the same period, the annual electricity consumption per capita increased by 4882 kW h (5.548%). During the period 1980–2007, the GHG emissions were doubled with an average annual increase rate of 1.8%. In 2008, the energy related emissions accounted for 82% of the total amount in which the power generation plants contributed to 55% of this total amount.

Table 10
Heating degree days [65].

Heating degree days (hdd)					
	hdd > 2000	2000 > hdd > 1500	1500 > hdd > 1300	1300 > hdd > 1220	1220 > hdd
Islands	Samothrace	Lemnos Lesbos Chios Skopelos Skyros	Milos Syros Kos Paros Andros	Tylos Naxos Amorgos Irakleia Koufonisi Shinousa	Rhodes

Table 11
Classification of some major islands by cost of produced energy [65].

Cost of produced energy (€/kW h)				
	Non interconnected			**Interconnected**
	> 0.30	0.30–0.15	0.15–0.10	(≈0.07)
Islands	Kythnos Amorgos Patmos Skyros Sifnos Milos	Lemnos Rhodes Santorin Kos Lesbos Syros	Chios Paros Naxos Ios Sikinos Folegandros	Aegina Alonissos Andros Kea Samothrace Skopelos

Table 12
Proportion of old buildings constructed before 1981 [65].

	Very high	**High**	**Medium**	**Low**
Islands	Lesbos Kimolos Lemnos Sifnos	Chios Samothrace Andros Patmos Kea Milos	Syros Amorgos Skopelos Naxos Skyros Rhodes	Irakleia Shinousa Ios Santorin Kos Paros

Table 13
Potential of energy savings in the residential sector.

Potential of energy savings in the residential sector				
	Very high	**High**	**Medium**	**Low**
Islands	Lesbos Lemnos Samothrace Chios	Andros Patmos Kea Kimolos Sifnos Skopelos	Skyros Milos Folegandros Kos Santorin Paros	Ios Kythnos Rhodes Naxos Syros Amorgos

The target of the Hellenic energy policy is the discovering, managing and securing of the energy resources in order to cover the national energy demand in the optimum way. Also, energy policies are focused toward the creation of alliances and alternative paths, in the attempt to meet the domestic energy market needs. The strategy for meeting the country's energy demands includes setting national targets for increasing the penetration of RE in the energy mix, creation of positive investment opportunities, saving energy actions for buildings, liberation of energy market, FIT establishment and others.

The RE potential in Greece is very high especially in the cases of solar and wind resources, with the average annual solar radiation varying around 1570 kW h/m^2 and the winds blowing at 62–88 km/h. The participation of RES in the gross electricity consumption reached 10.3%, in 2008; and the primary energy production by RES was increased by 60% between 1990 and 2008. In Greece, the target is to generate 20% of the electricity from RES. The main barriers in achieving this target are misguided interventions related to spatial plan for RES, the lack of information provided to citizens about relevant issues and the failure to involve local communities and authorities in the spatial planning procedure.

The Greek building sector is responsible for about 40% of the total final energy demand. The average annual growth rate of energy consumption in the Hellenic buildings during the period from 1985 to 2005 is estimated to be 4.5%. The fossil fuel use was increased by 100% from 1990 to 2007. The buildings built before 1980 (year of establishment of the insulation code) account for 74.6% of the total building stock.

The Aegean Sea region is very rich in RES. In 2008, the installed capacity accounted for 900 MW with only 71 MW to be installed in the Aegean Sea. The electricity generation in islands mainly depends on oil. Under proper introduction and application of innovative technologies, the local energy demand could be fully covered by RES. The southern parts of the Aegean Sea have higher annual average solar irradiation and wind speeds. The islands of Rhodes, Kos, Amorgos, Karpathos and Andros were found among the islands with the higher potential. As in the rest of the country in the Aegean Sea region there are barriers that decelerate the implementation of RE technologies. The main obstacles are the limitation in the grid infrastructure, license complexity, local community reactions, environmental concerns and lack of financial advantages to support RES investments.

Categorizing the islands based on energy production cost, heating degree days and proportion of old buildings in the building stock could help to focus any proposed actions. It was obtained that islands with the higher potential energy savings in the residential sector were Lesbos, Lemnos, Samothrace, Chios, Andros, Patmos, Kea, Kimolos and few others, while at the same time, Rhodes, Naxos, Amorgos, Syros, Ios and Kythnos were those islands that present the lower potential. The study will help to propose action plans and implementation strategies in terms of residential renewable energy applications in non-grid interconnected islands in Greece.

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